Research Article

Use of Corrosion Inhibitors in Stainless Steel Anchors Used in Glass Fiber Reinforced Concrete (GRC) Precast Facade Elements

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Abstract

Corrosion is the process of losing the physico-mechanical properties of the metallic material over time as a result of chemical or electrochemical reactions. It is one of the most fundamental problems encountered in the construction industry; according to the latest research despite all the precautions taken corrosion causes an economic loss of approximately 546 million pounds per year. In addition to financial consequences, numerous dramatic damage events are directly or indirectly attributed to corrosion process. Revealing the corrosion risk at the architectural design stage, taking into account the compatibility of the materials to be used, will contribute significantly to the steps to be taken regarding the monitoring and prevention of corrosion. In this study; the benefit of preventing the corrosion that occurs over time in the stainless steel anchors used in glass fiber reinforced concrete (GRC) precast facade elements by using corrosion inhibitor before mounted to the GRC was investigated. Creating a protective layer on the metal surface by using a patented chemical solution containing a corrosion inhibitor was used for the first time in the GRC sector in this study. After washing with corrosion inhibitor solution, stainless steel anchor elements were immersed in 5%(w/v) NaCl solution. After 30 days, the metal surfaces were examined by visually and were investigated by surface imaging methods (Scanning Electron Microscopy (SEM), Energy Dispersive X-Ray Spectroscopy (EDS)) and Atomic Force Microscopy (AFM). The findings show that washing with a solution containing corrosion inhibitor, especially after welding; increase the strength of the oxide film formed on the stainless steel surface and protects it against corrosion.

Keywords: *GRC, Stainless Steel, Corrosion, Inhibitor*

1. Introduction

Metals and metal alloys undergo chemical change by entering into chemical and electrochemical reactions with their environment. This phenomenon is called corrosion (Onaran, 1991). Unpreferred changes in the physical, electrical and chemical properties of metals or alloys due to corrosion cause significant financial losses (Slepski et al, 2014). Various methods are used to protect metals from corrosion. Choosing the most effective method for the metal being worked will make a positive contribution to the economy as it will prolong its service life. Glass fiber reinforced concrete (GRC) is used in various fields in the construction industry due to its high mechanical and physical properties. It has many usage areas, especially facade cladding and architectural applications. Metal elements are used in the assembly of GRC facade panels to the main building (Figure 1). The type of these metal elements can be determined according to the material dimensions, form and project characteristics. Stainless steel anchors are generally used in the embedded anchors of GRC facade panels (Figure 2).

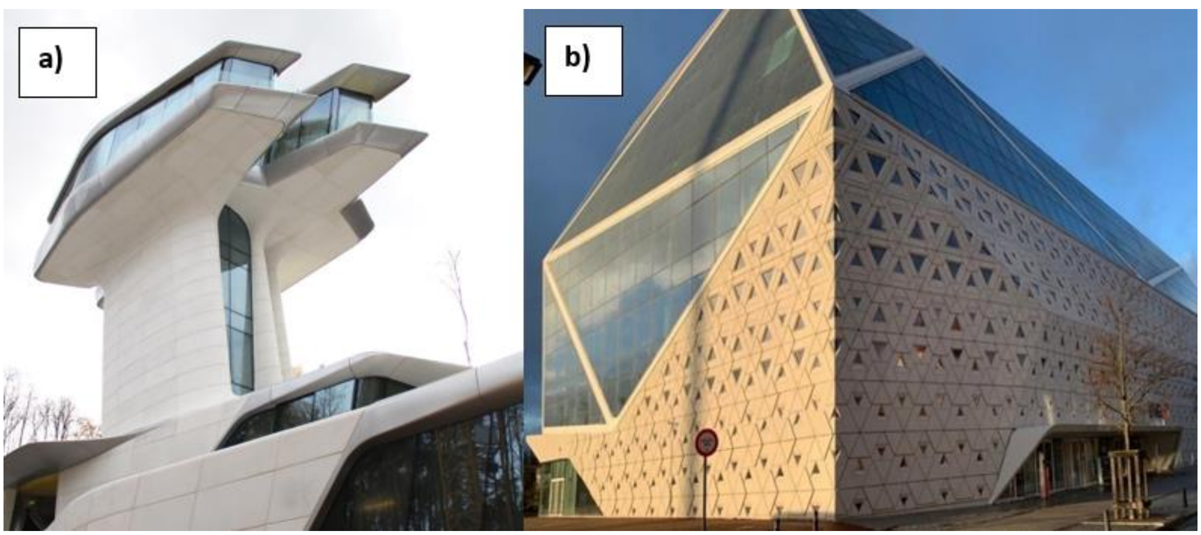


Figure 1. Use of GRC panels (Fibrobeton, 2022) a) Capital Hill Residence, Zaha Hadid Architects / Moscow b) Ghent Diamond, Asymtotes Architects / Brussels

Stainless steels are highly preferred engineering material due to their long service life, high corrosion resistance and high mechanical properties. Stainless steel products go through cold rolling after heat and surface treatment processes. Chemical and electrochemical processes can be preferred for cleaning stainless steels from high temperature oxides. Electrochemical processes are more controllable and costly (Güraydın, 2022). Corrosion inhibitors are substances that significantly reduce the rate of corrosion. Corrosion inhibitors should adhere to metal surfaces and form a protective film layer on the surface (Öztürk, 2018), (Bağcı, 2018), (Figure 3).

Figure 2. Stainless steel anchor elements

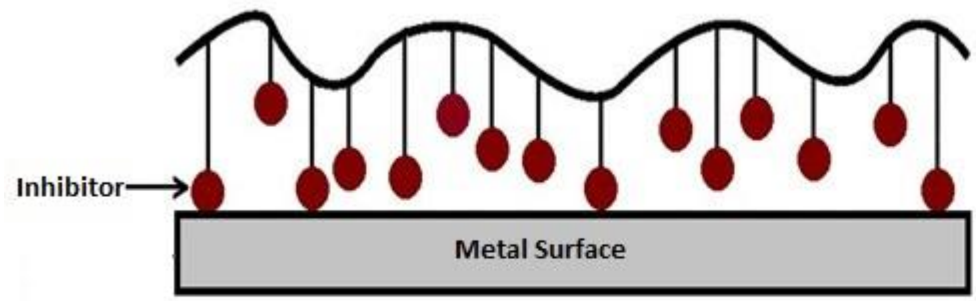


Figure 3. Adsorption of inhibitors to the metal surface

Corrosion inhibitors reduce the reactions that occur at the metal interface with the environment of metals exposed to corrosion. Inhibitors are inevitably used in many systems such as coolants, fuels, hydraulic fluids, metal oils and boiler waters (Sanyal, 1981). There are many scientific studies on corrosion inhibitors. In addition, there are definitions and lists of numerous chemical compounds as inhibitors in the literature. But only a few of them are used in practice. Factors such as cost, toxicity and environmental friendliness of inhibitors limit their desired use (Khalifa et al, 2003), (Gengi et al, 2012).

In this study, a corrosion inhibitor with an ecological composition registered to the Turkish Patent and Trademark Office with the application number 2017/12440 was used for the first time to prevent corrosion of stainless steel anchor elements used in the GRC sector.

Washed and unwashed stainless steel anchor elements with the patented solution were immersed in 5%(w/v) NaCl solution for 30 days then the samples were scanned by Scanning Electron Microscope (SEM), Energy Dispersive X-Ray Spectroscopy (EDS) and

Atomic Force Microscope (AFM) surface imaging systems. As a result of this study, it has been observed that the corrosion resistance of stainless steel anchors washed with the patented corrosion inhibitor solution decreases the corrosion rate.

2. Material and Methods

316 L stainless steel has very highly resistant properties against corrosion (Akgul et al., 2017). Therefore, 5%(w/v) NaCl medium, which is a highly corrosive medium, was chosen as the experimental medium (Ravi Kumar V. et al, 2019). The geographical location of the building where the panel cladding will be made is very important due to corrosion phenomena. Corrosion-resistant material such as 316 L stainless steel as anchor element should be chosen so that the holding panels of these panels do not corrode quickly (Fibrobeton, 2022) (Figure 4).

Figure 4. Stainless steel (316 L) GRC panel applications

The sample washed with a solution containing corrosion inhibitor and the reference sample were kept separately in 10 lt container in containers containing 5%(w/v) NaCl at room temperature for 30 days (Figure 5) and then, after drying in the desiccator for 3 hours, surface analyses have been made.

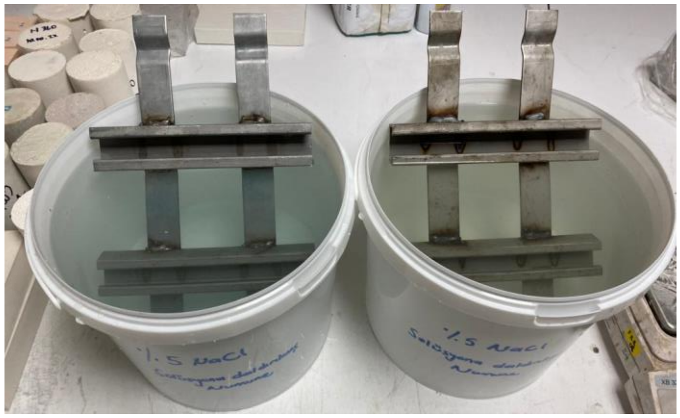


Figure 5. Experiment setup of keeping the washed and unwashed samples with solution containing corrosion inhibitor in 5% (w/v) NaCl environment

One of the simplest and easily methods used to determine the corrosion rate is to examine the observed corrosion-related changes in metal morphology visually and with advanced surface imaging methods such as SEM and AFM (Lahbib et al, 2021). The experiment plan is shown in Figure 6.

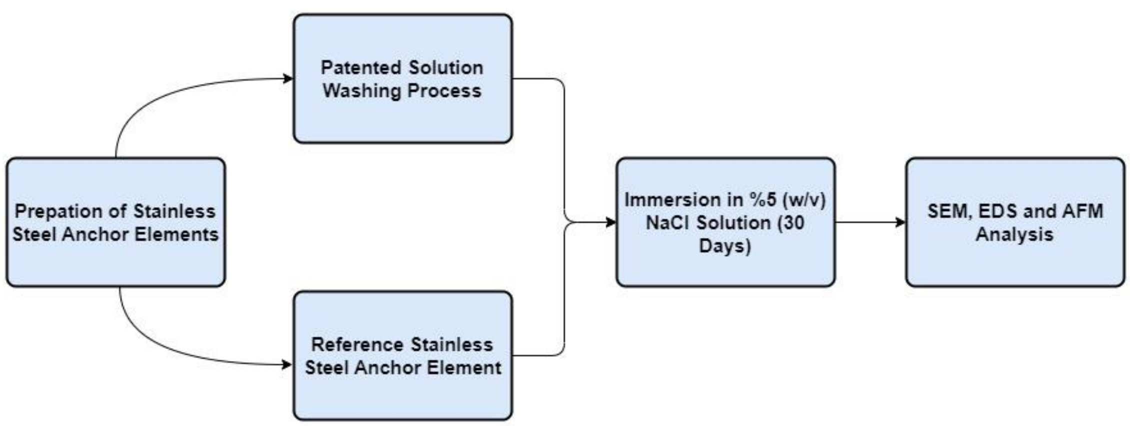


Figure 6. Experiment flow planning

2.1. SEM /EDS Analyses

The surfaces of the stainless steel anchor samples were examined by SEM and EDS analysis using J. Quanta FEG 250 (FEI, Holand) model device after removing from 5%(w/v) NaCl environment (Figure 7). SEM-EDS analyses were carried out by applying an acceleration voltage of 20 KeV in high vacuum mode by mounting the samples on an aluminium sample holder with double-sided carbon tape. Quantitative element distribution analysis was performed using X-ray microanalysis to determine material-specific elements on the surface of the samples.

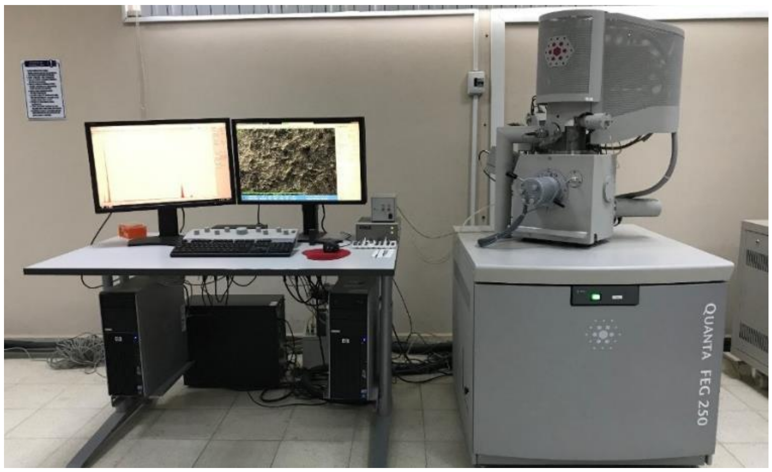


Figure 7. SEM / EDS analyses setup

2.2. AFM Analyses

The changes occur due to corrosion on the metal surface were examined with the Park system XE-100E model AFM device shown in Figure 8. AFM Analyses were applied in a 5x5 μm scanning area using non-contact mode to determine the roughness values occurring in the surface morphologies of the samples.

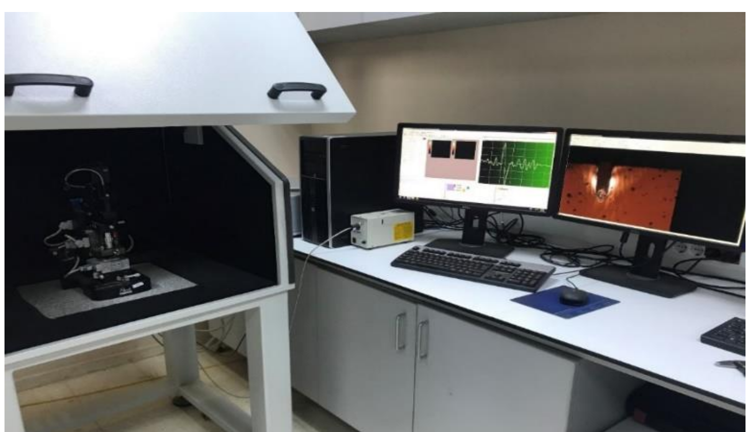


Figure 7. AFM analyses setup

3. Findings and discussions

In order to prevent corrosion that occurs over time in the stainless steel anchors used in glass fiber reinforced concrete (GRC) precast facade elements, a protective layer was formed on the metal surface by using a corrosion inhibitor before the anchor elements were mounted to the GRC. The benefit of the layer created on the anchors was investigated in this study. A patented chemical solution containing corrosion inhibitors was used for the first time in the GRC industry.

Stainless steel anchor elements, washed with patented chemical solution and unwashed were exposed to 5%(w/v) NaCl solution for 30 days. Images of the 7th and 30th days of exposure are shown in Figure 9 and Figure 10.

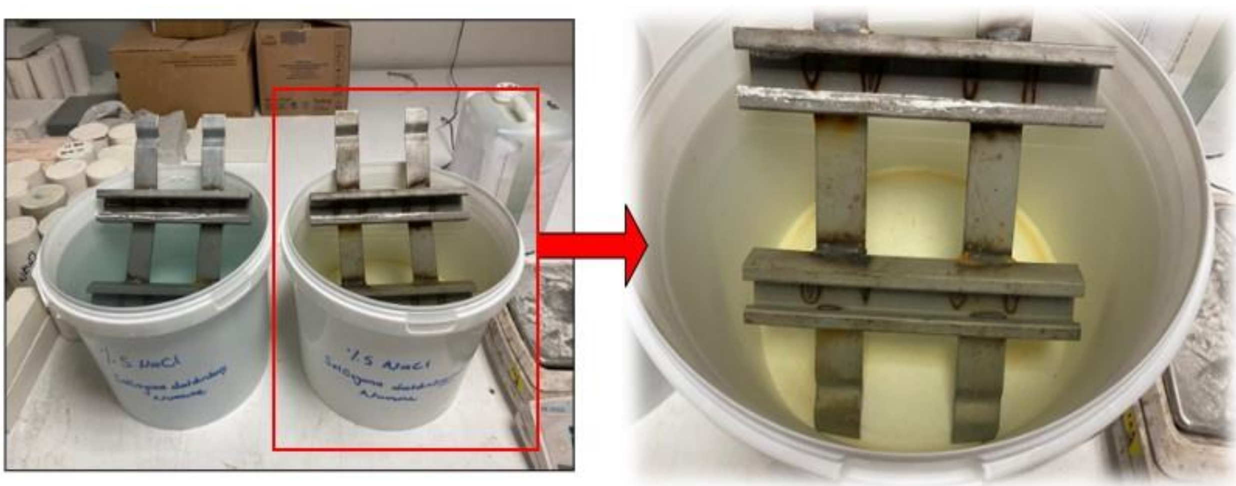


Figure 9. Stainless steel anchor samples after 7 days in 5%(w/v) NaCl medium

After 30 days of exposure, the anchor samples were removed from the solution and visually inspected (Figure 11 and Figure 12). As can be seen, the corrosion of the anchor element, which was washed with the solution, was extremely low compared to the reference sample. Especially the presence of corrosion in the weld area reveals the potential to cause a decrease in load carrying capacities and possible work accidents in the future. Corrosion of these anchor elements, which carry panels with an average weight of 600 kg (Figure 4), is an undesirable situation in terms of work safety.

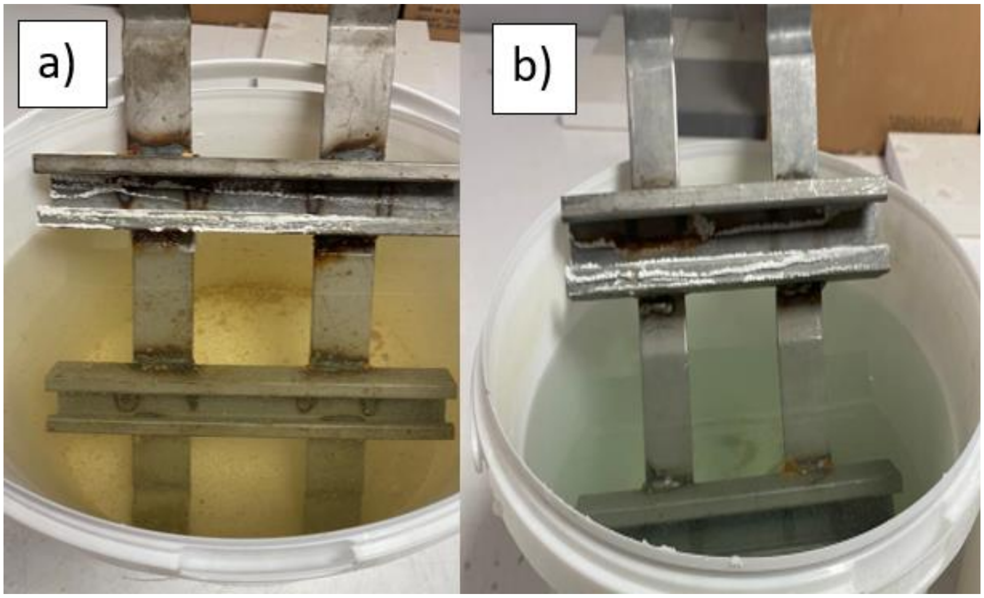


Figure 10. Stainless steel anchor samples after 30 days in 5%(w/v) NaCl medium a) Not washed with solution b) washed the patented corrosion inhibitor solution

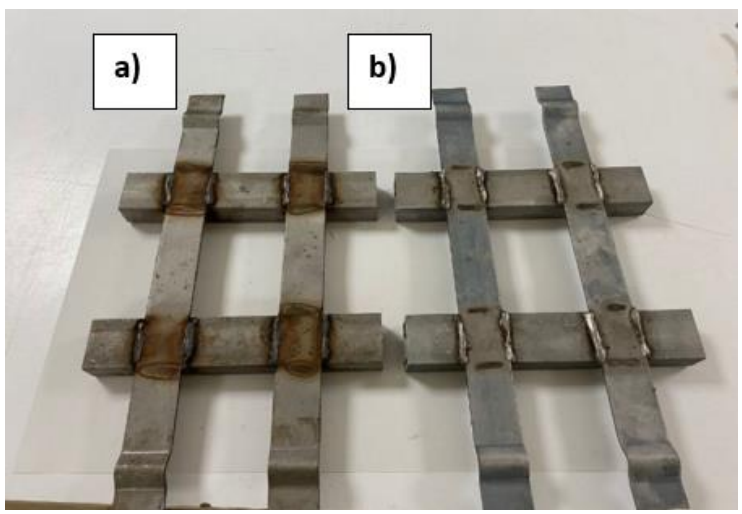


Figure 11. Front surface of stainless steel anchoring surfaces after 30 days in 5%(w/v) NaCl medium a) Not washed with solution b) washed with the patented corrosion inhibitor solution

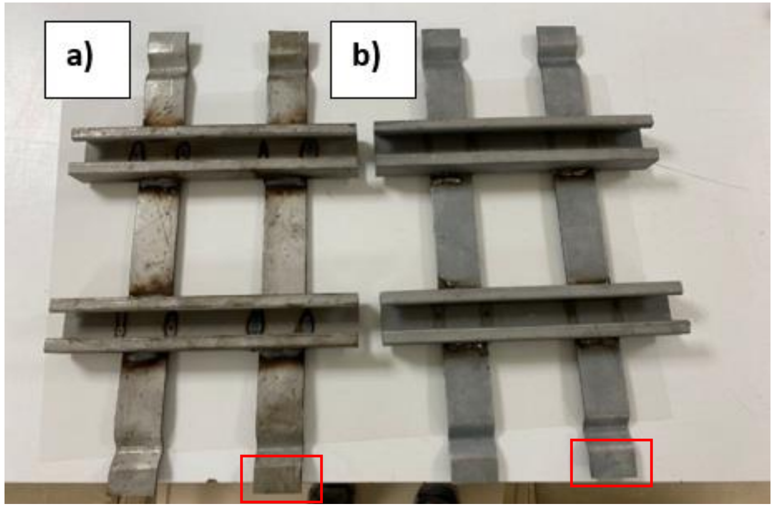


Figure 12. Back surface of stainless steel anchoring surfaces after 30 days in 5%(w/v) NaCl medium a) Not washed with solution b) washed with the patented corrosion inhibitor solution

The marked lower right parts of the samples (Figure 12) in the solution were carefully cut with 6x6 cm iron scissors and used for SEM/EDS and AFM analyses.

3.1. SEM /EDS Analysis Results

The SEM/EDS results of the sample that was not washed with the ecological corrosion inhibitor registered with the Turkish Patent and Trademark Office with the application number 2017/12440 are shown in Figures 13 and 14. As can be seen in Figure 13, it is seen that corrosion products are formed on the metal surface intensively. When the oxide layer formed is analysed by EDS (Figure 14), it is seen that the layer formed on the metal surface consists of a high amount of oxygen (31%) and iron (21%). The density of these two elements proves that the iron in the composition of the working electrode forms an oxide layer with oxygen (M. Bernable et al, 2022). The presence of sodium (4%) and chlorine (4%) elements on the metal surface, which are found outside the metal composition, is due to the environment in which the experiment was performed (5% (w/v) NaCl).

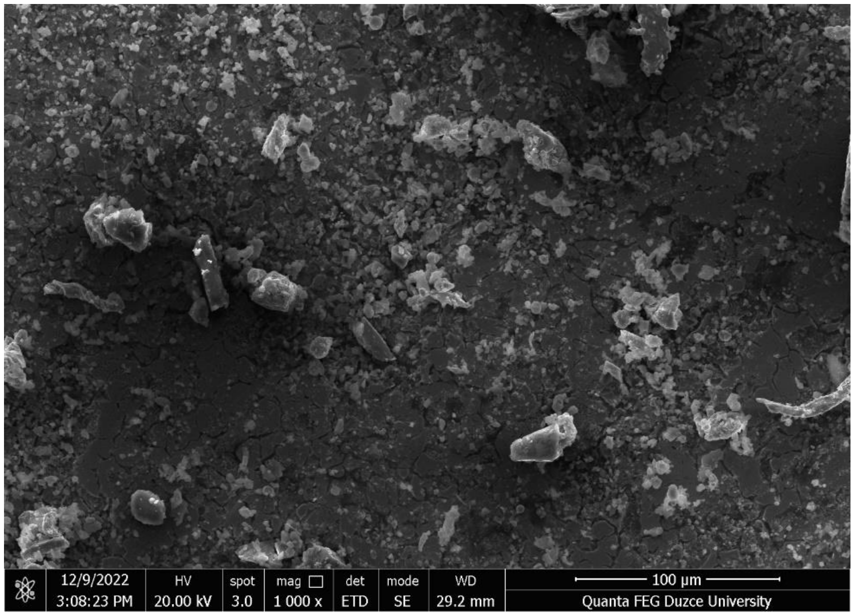
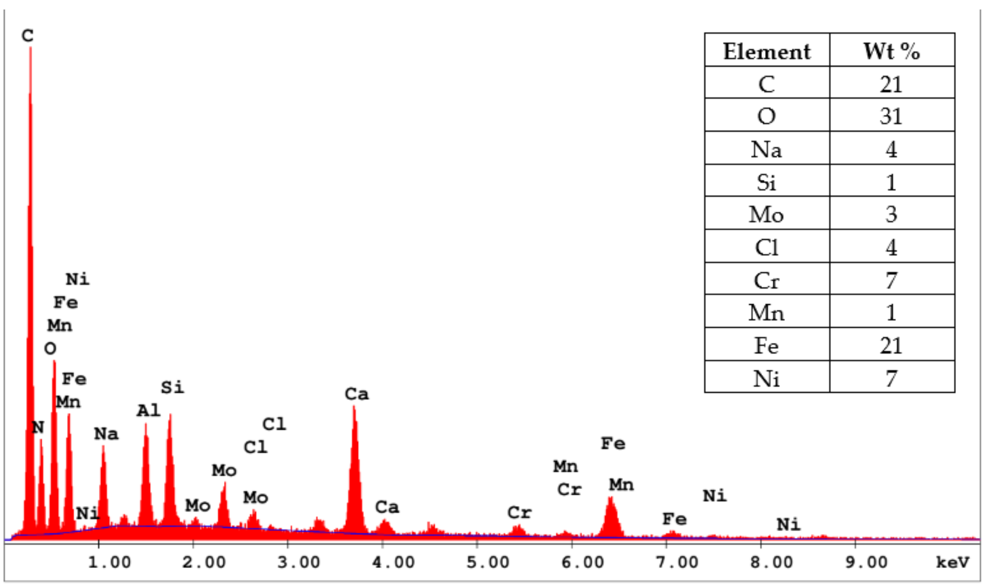


Figure 13. SEM image of the reference sample that has not been washed with the patented solution



Element	Wt %
C	21
O	31
Na	4
Si	1
Mo	3
Cl	4
Cr	7
Mn	1
Fe	21
Ni	7

Figure 14. EDS analysis of the reference sample that has not been washed with the patented solution

The SEM/EDS results of the sample washed with the solution containing a corrosion inhibitor (patented solution- application number 2017/12440) are shown in Figures 15 and 16.

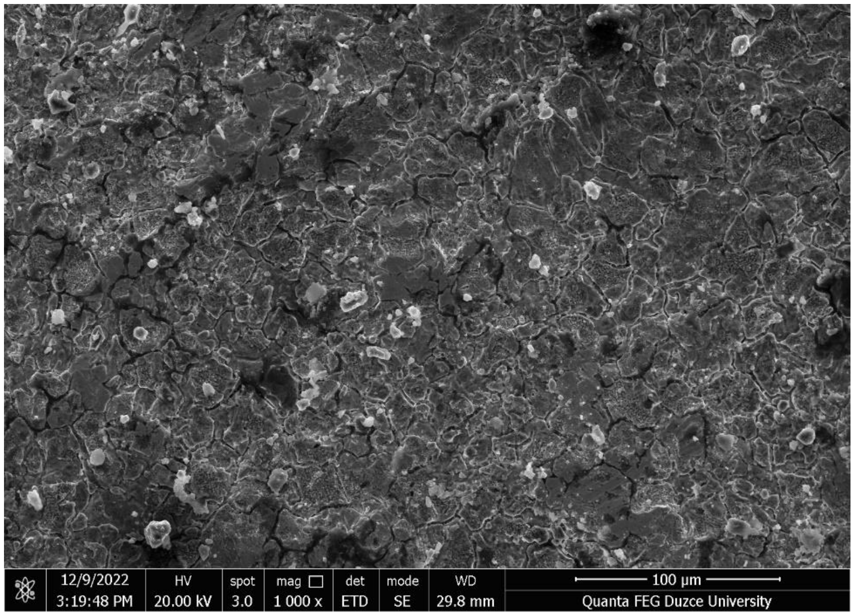
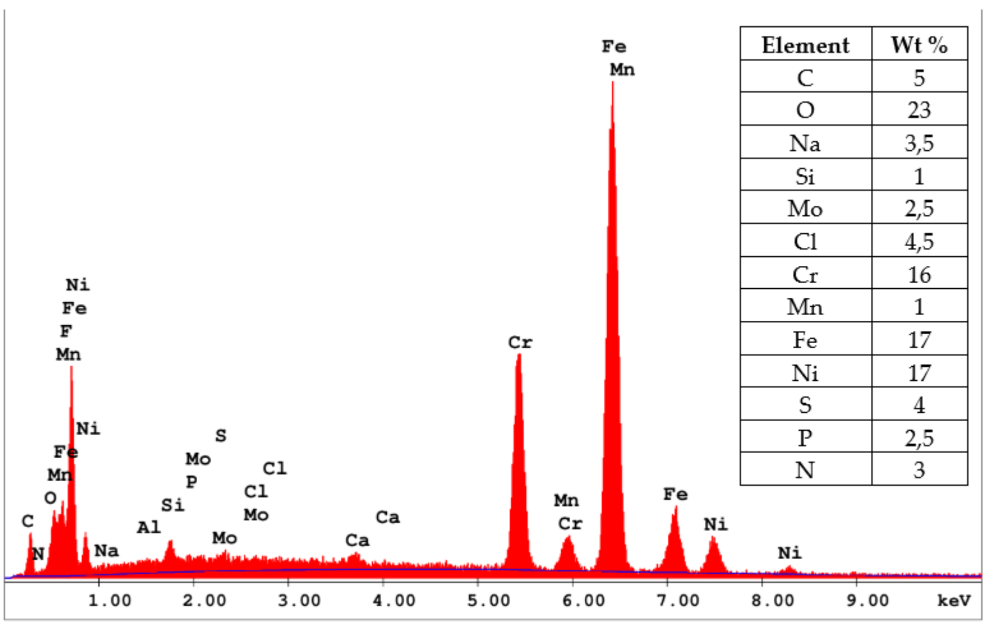


Figure 15. SEM image of the sample that has been washed with a solution containing a corrosion inhibitor



Element	Wt %
C	5
O	23
Na	3,5
Si	1
Mo	2,5
Cl	4,5
Cr	16
Mn	1
Fe	17
Ni	17
S	4
P	2,5
N	3

Figure 16. EDS analysis of the sample washed with a solution containing corrosion inhibitor

It is seen that a more homogeneous oxide layer is formed on the surface of the sample that has been washed with a solution containing corrosion inhibitor (Figure 15). The increase in the chromium ratio (Figure 16) indicates the chromium oxide (Cr_2O_3) layer, which is the passive film, formed on the surface of the 316 L stainless steel samples. Unlike the EDS analysis of the unwashed reference sample (Figure 14); The presence of sulphur (4%), phosphorus (2.5%) and nitrogen (3%) proves that the inhibitor in the ecological corrosion inhibitor registered with the Turkish Patent and Trademark Office, which we use to prevent corrosion, with the application number 2017/12440, forms a layer on the metal surface.

3.2. AFM Analysis Results

The AFM analysis results of the untreated sample that was not washed with the corrosion inhibitor are given in Figure 17. At the end of the test, it is seen that deformations occur on the surface of the reference sample due to corrosion. Two parameters (Ra and Rz) expressing the surface roughness are shown in Table 1 (H. Gerengi et al, 2019). The Rz value of the sample that has not been washed with the solution is 1059 nm, while the Ra value is 243 nm. These values decreased to 512 and 228 nm, respectively, after chemical pre-treatment process. The higher change observed in the Rz value indicates that the distance between the peak and the low valley at the 5 highest points in the sample area measured is high. This finding indicates pitting corrosion.

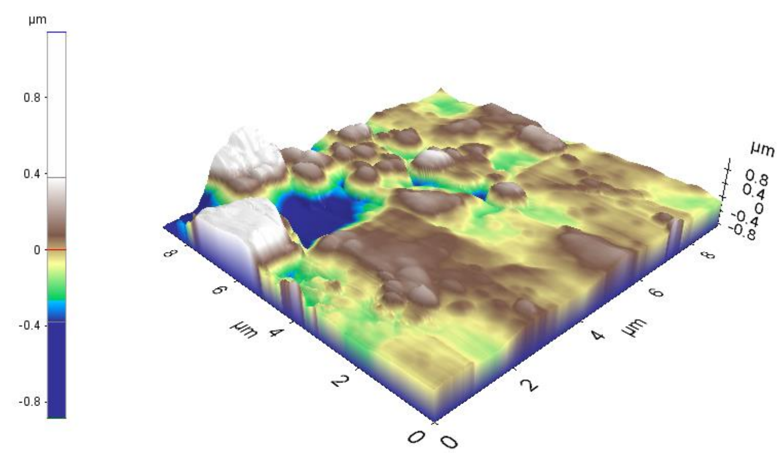


Figure 17. AFM analysis of the reference sample that has not been washed with the patented solution

Sample	Ra (nm)	Rz (nm)
Untreated Sample	243	1059
Sample washed with the patented solution	228	512

Table 1. AFM analysis results

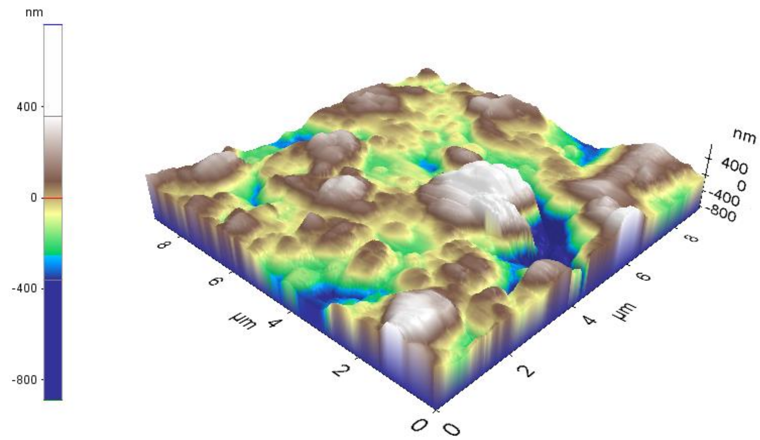


Figure 18. AFM analysis of the sample washed with the patented solution

It is seen in Figure 18 that washing with a solution containing corrosion inhibitor contributes to the formation of a homogeneous surface on the morphology of the metal. It can be seen from Table 1; lower Ra and Rz values compared to the reference sample indicate that the surface is less deformed.

4. Conclusion

Treated and untreated with the patented corrosion inhibitor solution, stainless steel anchor elements were immersed in 5%(w/v) NaCl solution and after 30 days the metal surfaces were investigated visually and by using advanced surface imaging methods (Scanning Electron Microscopy (SEM), Energy Dispersive X-Ray Spectroscopy (EDS)) and Atomic Force Microscope (AFM)) results led to the following conclusions:

- ✓ In this study, an ecological corrosion inhibitor registered with the Turkish Patent and Trademark Office with the application number 2017/12440 was investigated for the first time for stainless steel anchor elements. SEM-EDS-AFM analyses show that the patented corrosion inhibitor solution protects the investigated metal from corrosion by forming a barrier on the metal surface.
- ✓ AFM analyses show that washing with a solution containing a corrosion inhibitor causes a decrease in roughness values (Ra and Rz), especially protecting against pitting corrosion. This finding shows that the solution used provides a more homogeneous surface on the metal surface.
- ✓ The visual findings obtained at the end of the first, seventh and thirtieth days showed that the washing with the solution containing the corrosion inhibitor successfully protected even in the highly corrosive environment of 5%(w/v) NaCl

after 30 days. The fact that the colour change on the metal surface and in the solutions in which the samples are placed is quite limited proves this finding.

- ✓ This scientific study proves that a simple pre-treatment process for stainless steel anchor elements used in GRC applications can be a solution to corrosion phenomena, which is considered one of the most important problems in the construction sector.

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